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Water Resources of the Northeast National Petroleum Reserve-Alaska

Jon Kostohrys, Valerie Barber and Tim Hammond

Cover Photo
Kalikpik River at the mouth, flowing into Harrison Bay.

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Abstract

During June and July of 1999, the BLM collected streamflow, channel geometry and water quality data in northeastern NPR-A. This information was used to supplement a GIS basin analysis of watershed characteristics of this area. The hydrologic maps, channel geometry, and water quality information will be used to define watershed characteristics of areas open to oil lease activity, and to mitigate the potential disturbances from these activities.

Acknowledgments

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INTRODUCTION

In October 1998, the Bureau of Land Management issued a Record of Decision (ROD) regarding the Northeast National Petroleum Reserve-Alaska Integrated Activity Plan/Environmental Impact Statement (IAP/EIS). The ROD for management of this area, while setting aside special areas of no surface disturbance and limiting certain activites, still allows for oil and gas exploration leasing within the planning area. To ensure compliance of the plan's stipulations, the ROD notes that monitoring will be undertaken to determine the status of the various resources within the area and to measure the effectiveness of the stipulations and mitigative measures within the plan.

Numerous stipulations within the IAP/EIS (Chapter II) limit surface-disturbing activities on lakes and rivers. The intent of the Inventory and Monitoring Plan is to minimize undue and unnecessary degradation to water resources in the planning area and adjacent watersheds, using hydrology and limnology to identify critical aquatic habitat areas for fisheries and waterfowl. Both fieldwork and Geographic Information System (GIS) mapping are necessary. To meet these requirements, hydrologic and limnologic field surveys were conducted during June and July 1999. Additionally, a GIS map and database was developed for the water resources of the planning area. For more information on the ROD and IAP/EIS, the reader is referred to USDI 1998a and USDI 1998b; listed in References.

DESCRIPTION OF STUDY AREA

The Northeast National Petroleum Reserve-Alaska is located on the northern coast of Alaska (Fig. 1). In general, this area is bounded by the Arctic Ocean to the north, the Ikpikpuk River to the west, and the Colville River to the south and east, excepting portions of the headwaters of the Ikpikpuk and Colville River in the foothills west of Umiat. Physiography and climate are the dominant factors influencing the water resources within the planning area.

Physiography

As defined by Wahrhaftig (1965), the Northeast NPR-A contains two primary physiographic regions: the Arctic Coastal Plain, which comprises most of the area, and the Arctic Foothills of the Brooks Range.

The Arctic Coastal Plain is underlain by ice-rich marine sediments, the result of numerous marine transgressions and recessions (Sellman et al. 1975). Permafrost, perennially frozen ground, is virtually continuous throughout the planning area. Permafrost prevents infiltration of surface water, forms a largely saturated active (thawed) soil layer and isolates the much deeper ground water of the area (Sloan 1977). Disturbance and thaw settlement of the perennially frozen ice-rich sand and silt has created a mosaic of lakes, ponds and interconnected streams (beaded drainages). The thaw lake cycle (Sellman et al. 1975) creates a continuously changing landscape as lakes form, expand and drain in response to disturbance of the permafrost terrain. The limited relief of the coastal plain also results in low-gradient, meandering and braided streams, and shallow-water tracks (surface flow unconfined by channels) that can convey significant discharge in these areas (Hinzman et al. 1993). Portions of the central and eastern coastal plain are underlain by low, undulating sand dunes. These relic Pleistocene eolian dunes are generally stabilized by vegetation, although numerous active blowouts along bluffs bordering streams and lakes indicate that this terrain is easily disturbed and subject to renewed erosion (Carter and Galloway 1979). These dunes provide a rich sediment source for many of the streams in the area.

The Arctic Foothills of the Brooks Range form the southern portion of the planning area. The foothills begin as a band of low hills at approximately the 500 foot elevation, adjacent to the coastal plain, and terminate on the high bluffs of the Colville River. Lakes are rare. River valleys are narrower and streams have a much steeper gradient than those on the coastal plain. The rolling hills and mesa-like table lands are a sharp contrast to the mosaic of lakes and wetlands to the north. Ice-rich permafrost soils are still abundant in low-lying areas, but steeper valleys, ridges and higher hilltop soils often consist of well-drained gravels and weathered bedrock.

Climate

The climate of the area is divided into three zones: Arctic Coastal, Arctic Inland and Arctic Foothills (Zhang et al. 1996). All three zones have short, moderately warm summers and long, very cold winters. The inland area, which comprises most of the planning area, has the most extreme climate, with both the lowest winter and highest

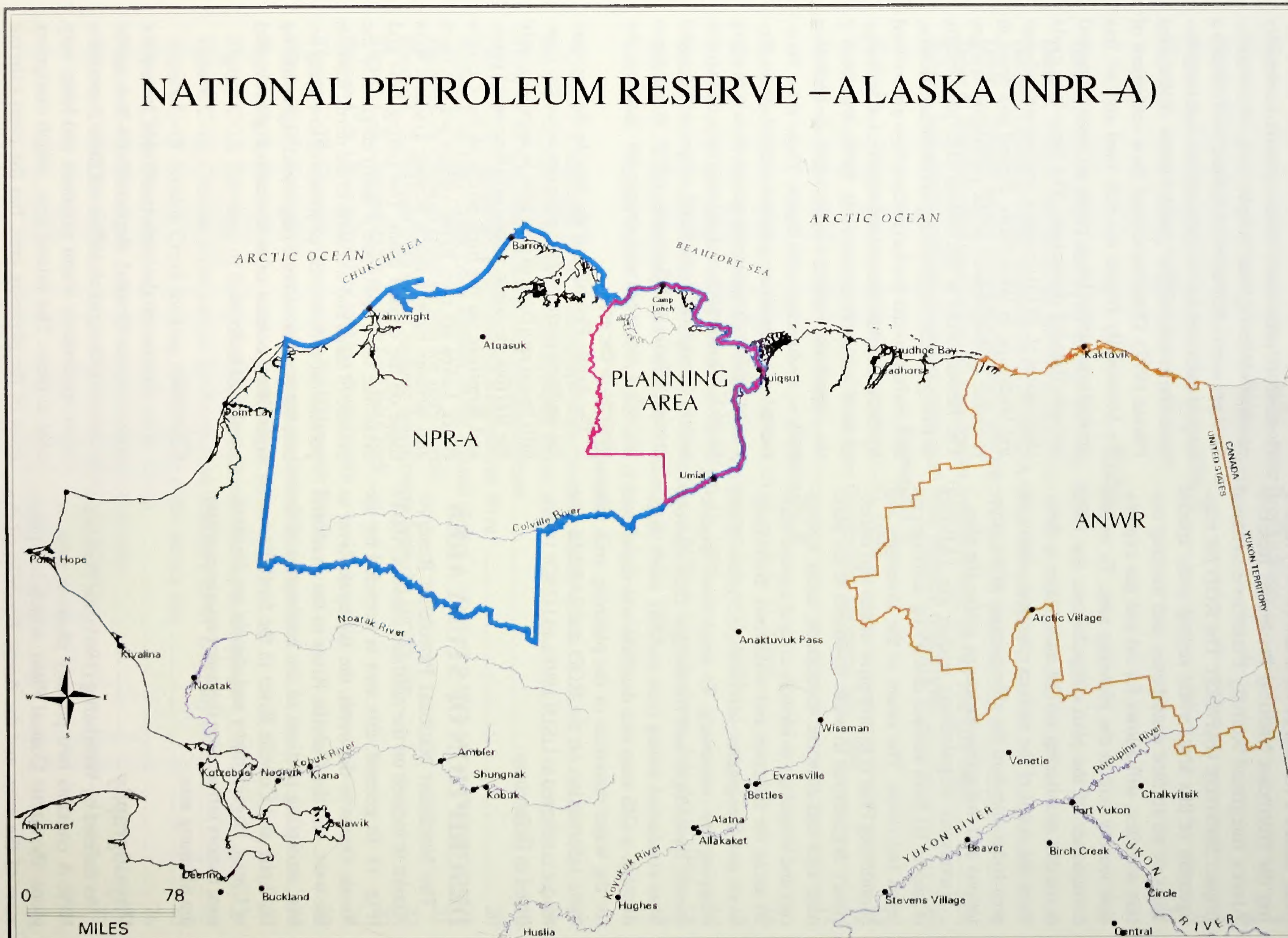

Figure 1. Map of Northern Alaska, NPR-A and Northeast Planning Area.

summer temperatures. Annual precipitation ranges from over 12 inches in the foothills to less than 8 inches along the coast, about half of which falls as snow. The snowpack is highly variable due to the extreme winter winds that scour snow from exposed ridges and hilltops and form drifts along protected side slopes and valley bottoms (Sloan 1977). Summer precipitation is usually light, but heavy rainstorms do occur, most often during July or August in the inland and foothills areas.

METHODS

Geographic Information System

Development and analysis of the drainage basins was performed using Arc/Info geographic information system software.

Terrain modeling: The 144 USGS 15-minute series digital elevation models (DEMs) for the Harrison Bay, Umiat, Ikpikpuk River, Teshekpuk Lake, Meade River and Lookout Ridge quadrangles were merged to produce a 60-meter resolution DEB of the entire study area.

USGS DEMs often contain errors, due to sampling and rounding effects, that create hydrologic sinks (areas showing no drainage). These sinks interfere with hydrologic analyses performed in a GIS, and filling them is a standard practice prior to using DEMs for hydrologic analyses. Filling sinks is an iterative process involving five steps:

1. Determine the direction of flow for each grid cell in the DEM.
2. Locate all sinks in the DEM.
3. Find the contributing area to each sink.
4. Find the depth of each sink.
5. Fill the sinks to the level of the lowest neighboring grid cell.

The process is repeated until there are no remaining sinks. Arc/Info's GRID module provides prewritten routines to facilitate each of these steps.

This process produces two new data layers: a "hydrologically corrected" digital terrain model (DTM) and a corresponding grid in which the cell values represent the direction of flow for each grid cell in DTM. These are both used in the hydrologic modeling process.

Hydrologic modeling: The flow direction grid is used to determine the flow accumulation, or the total number of cells that drain into each grid cell. A threshold is applied to the flow accumulation grid to determine which grid cells represent stream channels. In this exercise, choosing all grid cells with a flow accumulation of 500 or more grid cells produced a reasonable approximation of streams in the study area.

Gaging sites were entered using coordinates collected in the field using global positioning system receivers. These points were moved to the nearest grid cell within 300 meters of the digitized location and in a stream channel, as determined above. This method ensures that the gaging site will be in the stream network represented by the terrain model. The mouths of all major streams within the planning area were also mapped to determine basin properties for the entire planning area. Where streams terminated in deltas, the location of the main channel and mouth were confirmed with aerial photography. For the Ikpikpuk distributary system, locations are approximate due to the extremely complex nature of the channel network and because most of these distributaries (Chipp and Alaktak rivers) are outside the planning area.

Using a pre-written routine in Arc/Info, the flow direction grid was used to determine groups of cells that drain to the same gaging site. This provided an initial approximation of the contributing areas to each gaging site. The perimeter of each contributing area was plotted over USGS 15 Minute Digital Raster Graphic (DRGs). Errors in the basins were identified by the hydrologist using these plots and orthoquads derived from National Technical Systems. The basin perimeters were then manually edited to produce perimeters for the area contributing exclusively to each gaging site. The immediate contributing area to each gaging site was combined with the contributing areas for all upstream basins to produce a perimeter for the total contributing basin to each gaging site. The perimeters are stored as polygons in a GIS database. The area and perimeter of each polygon is automatically generated in the polygon attribute table.

Terrain description: Each basin was converted to a raster data set at the same resolution as the DTM. Descriptive statistics (mean, minimum, maximum) about the population of DTM cells that fall within each basin were generated and stored in a database table.

Lake area determination: All lakes contained in the USGS 15 minute Digital Line Graph (DLG)

Figure 2. Rivers meander through numerous lakes on the Arctic Coastal Plain.

files were extracted into a separate GIS database. The union of each basin with the lakes was calculated. This, in effect, added the basin ID number to the polygon attribute table record for each lake within the basin. The area was summed for all lakes with the same basin ID number to determine the total area of lakes within each basin.

Determination of forested area: Pixels representing tall shrubs or low shrubs extracted from a land-cover classification produced from Landsat Thematic Mapper and SPOT XS satellite imagery (Ducks Unlimited, Inc., 1998) were used as an approximation of the forested portion of the study area. The raster version of each basin was combined with the forested area grid to produce an attribute table containing the number of 30x30 m forested pixels falling within the basin. This was used to calculate the total forested area within each basin.

Determination of stream miles: Stream miles for each basin were determined from 15 minute DLGs. Narrow streams are represented by single lines in the DLGs, but wider streams are represented by polygons. Thus, it was necessary to calculate the center lines of these polygons in order to perform stream mile calculations. Center lines were located by densifying the polygon perimeters to contain a vertex every 10 meters. These vertices were converted to point features, then Thiessen polygons were calculated for the set of points. The lines composing these polygons were clipped to the extent of the river polygons and, through a series of selections based on spatial adjacency and connectivity, all lines that were not centerlines were removed. The resulting centerlines were merged with the single-line streams from the DLGs. Gaps were visually identified and connected. The shortest contiguous path between each gaging station and its headwater was selected and placed into a separate coverage. The length of the lines in each coverage were calculated and converted to miles.

Hydrology

Twelve survey sites were preselected from topographic maps for streamflow and hydraulic geometry study prior to the trip in June. These were selected based on proximity to potential surface-disturbing activities as well as to provide a range of stream types and drainage areas representative of the planning area. At each site during this initial trip, high-water lines were marked and water samples and photographs were taken of the channel and surrounding areas. Limited fuel in the helicopter prevented a complete reconnaissance of the planning area, and only 10 sites were visited. In July, most of the sites were revisited and surveyed. Some new sites were established due to un-

Figure 3. Kogosukruk River in the foothills of the Brooks Range.

suitable low-flow channel conditions at the preselected sites. Other sites were not revisited due to time and logistical constraints. Thirteen sites in all were visited on the two trips, but only nine were surveyed for streamflow and channel morphology (Table 1).

To define a series of stream channel reference sites as well as to develop a hydrologic data base for the area, the format of the study chosen was similar to the hydraulic geometry surveys of Emmett (1972) and reconnaissance hydrologic surveys of Childers et al. (1977 and 1979) in their investigations in the Arctic. At each site, cross-sectional discharge (streamflow) measurements were made using a Price AA current meter to measure water velocity and a top-setting wading rod

Table 1. NPR-A rivers surveyed in June and July, 1999.

Site No.	Stream Site	Latitude	Longitude	Origin of Basin	Channel Type
1	Ikpikpuk River	69° 36.98'	154° 53.85'	Foothills	Meandering
2	Lower Ikpikpuk River*	70° 09.45'	154° 39.17'	Foothills	Meandering
3	Prince Creek*	69° 18.66'	152° 47.45'	Foothills	Meandering
4	Upper Kogosukruk River*	69° 35.77'	152° 09.98'	Foothills	Incised Meanders
5	Kogosukruk River	69° 39.86'	151° 48.91'	Foothills	Incised Meanders
6	Judy Creek	70° 03.96'	152° 25.65'	Foothills	Meandering
7	Fish Creek	70° 10.86'	152° 29.22'	Coastal Plain	Meandering
8	Ublutuoch River	70° 14.80'	151° 17.35'	Coastal Plain	Meandering
9	Kalikpik River	70° 20.13'	152° 15.33'	Coastal Plain	Braided
10	North Fork Kalikpik R.Trib.	70° 26.11'	152° 06.63'	Coastal Plain	Meandering
11	Kealok Creek	70° 20.58'	153° 16.29'	Coastal Plain	Braided
12	Lower Kealok Creek*	70° 27.15'	153° 18.14'	Coastal Plain	Braided
13	Teshekpuk Lake Tributary	70° 25.94'	154° 03.38'	Coastal Plain	Meandering

* Site not surveyed during July trip.

and tag line for depth and width, respectively (Rantz and others, 1982). The stream banks, high-water marks and water surface profiles were surveyed using a level and stadia rod (Benson and Dalrymple, 1967). The roughness coefficients (n values) were selected according to Barnes (1967). The bankfull determination followed the active floodplain definition of Leopold and Skibitzke (1967).

A water level vs. discharge rating was then developed by using the direct discharge measurement to verify parameters used in the computer generated streamflow model (Dalrymple and Benson, 1967). Information determined at each cross section included low-flow, instantaneous peak-flow of the 1999 high-water marks, and bankfull hydraulic-geometry relationships.

Bankfull geometry relationships for width and discharge were then developed following the regression methods usgd in Emmett (1972). Depth and velocity were not analyzed. Since no direct measurements of high streamflow were made, bankfull velocities were estimated from computer simulation. Depth along any one stream reach was often highly variable, with deep pools alternating with shallow riffles. This would have required numerous cross sections to characterize the reach, which was beyond the scope of this initial survey.

After the nine stream channel reference site locations were entered into a GIS database and the basin characteristics determined, peak flow statistics were then computed from the regional estimator equations listed in Jones and Fahl (1995).

Water Quality

Thirty lakes (Table 2) and 13 rivers (Table 1) were sampled on the two trips to provide baseline limnological information. During the June trip, water quality readings were taken with a Hydrolab multiparameter meter, which recorded water temperature, specific conductance, pH and dissolved oxygen. During July, a Horiba multiparameter meter was used for these same parameters plus turbidity and salinity. Additional samples were also taken from selected lakes for dissolved ^{18}O and CO_2 analysis. Zooplankton samples were collected, water was filtered for chlorophyll and isotope analysis, and hardness and alkalinity were determined. Filtered and unfiltered water samples were sent to Oregon State University for chemical and nutrient analysis.

Table 2. NPR-A lake locations surveyed July 6-11, 1999.

Lake Site	Latitude	Longitude	Depth Range*
1	70° 06.42'	152° 37.18'	b
2	70° 24.88'	153° 30.15'	b
3	70°19.77'	153° 11.78'	b
4	70° 25.79'	152° 02.69'	b
5	70° 25.88'	152° 04.08'	a
6	70° 25.36'	152° 09.60'	b
7	70° 26.58'	152° 04.41'	b
8	70° 26.88'	152° 04.13'	b
9	70° 27.06'	152° 01.24'	b
10	70° 26.35'	152° 02.65'	b
11	70° 25.42'	152° 00.59'	b
12	70° 25.10'	152° 02.32'	b
13	70° 24.92'	152° 12.68'	b
14	70° 22.67'	152° 20.54'	b
15	70° 16.40'	151° 22.19'	a
16	70° 23.72'	152° 26.80'	b
17	70° 23.77'	152° 28.97'	b
18	70° 22.25'	152° 27.03'	b
19	70° 21.58'	152° 29.81'	b
20	70° 25.17'	152° 30.31'	b
21	70° 25.23'	152° 31.92'	b
22	70° 26.21'	152° 33.51'	b
23	70° 25.13'	152° 39.22'	b
24	69° 57.44'	153° 13.16'	c
25	69° 53.95'	153° 21.98'	c
26	69° 50.86'	153° 29.38'	c
27	69° 40.77'	153° 45.09'	b
28	69° 43.60'	152° 02.55'	b
29	69° 51.61'	152° 23.66'	c
30	70° 00.76'	153° 04.59'	b

*Depth range from Mellor (1985)
a=Maximum depth less than 5 feet.
b=Maximum depth between 5 and 13 feet.
c=Maximum depth greater than 13 feet.

Figure 4. Lakes on the Arctic Coastal Plain.

Table 3. Drainage Basin Characteristics of NPR-A from GIS Analysis.					
Drainage Basin	River Length (miles)	Drainage Area (sq. mi.)	Mean Basin Elevation (ft.)	Area of Lakes & Ponds (%)	Area of Shrub Cover (%)
Ikpikpuk River	191.0	8,768	250	15.8	3.7
Kogosukruk River	77.9	543	416	1.7	4.8
Kikiakorak River	101.8	379	321	7.3	1.2
Judy Creek	143.3	709	209	16.0	0.5
Fish Creek	128.8	1,808	172	18.2	0.4
Inigok Creek	114.9	281	186	23.6	0.2
Kalikpik River	88.1	378	113	28.1	0.0
Ublutuoch River	72.6	212	121	11.6	0.5
Kealok Creek	87.3	375	136	27.2	0.0
Miguakiak River	173	1,448	63	40.4	0.2

RESULTS AND DISCUSSION

Geographic Information System

The hydrologic basin map, Figure 5, was generated from GIS analysis. The basin characteristics for all rivers identified during the IAP/EIS process (USDI 1998a), generated from this analysis, are listed in Table 3. For the specific stream gaging sites surveyed in July, the basin characteristics are listed in Table 4. As noted earlier, the channel determinations for the Ikpikpuk River and some of the coastal plain rivers that terminate in deltaic or distributary systems are approximate due to the extremely complex nature of the channel network. The lakes in the area, with sampling locations, are shown in Figure 6.

Hydrology

Appendix A contains discharge data at the nine surveyed sites for the low-flow, instantaneous peak-flow, and bankfull streamflow. A brief description of the stream reach at each survey site and graphs of the cross-sectional data used for the hydraulic models are in Appendix C. While the variation in the respective discharges might at first seem large, the diverse nature of some of the watersheds, especially the areas, mean elevation, lake and shrub percentages of the basin as listed in Table 4, would imply very disparate runoff characteristics. Childers et al. (1979) also noted large differences in bankfull discharge and peak runoff rates, such that they were unable to determine any clear relationships to drainage basin physiography or climate for the arctic streams in their wide-ranging data set.

Table 5 lists the regression relations for bankfull discharge and width as a function of drainage area. While the initial plan called for 12 sites, only nine were surveyed. Since Childers (1979) surveyed two sites (lower Ikpikpuk River and lower Fish Creek) within the planning area, data from these were also analyzed with the current data set. These regressions, using 11 sites (also listed in Table 5), show a higher correlation and lower standard of error than those computed with just the nine sites

Table 4. Stream Survey Site Characteristics of NPR-A from GIS Analysis.					
Stream Survey Site	At River Mile (miles)	Drainage Area (sq. mi.)	Mean Basin Elevation (ft.)	Area of Lakes & Ponds (%)	Area of Shrub Cover (%)
Ikpikpuk River	154.8	1,175	620	0.4	10.4
Kogosukruk River	41.2	446	455	0.7	5.5
Judy Creek	40.2	436	275	13.3	0.7
Fish Creek	73.0	683	184	22.5	0.3
Kalikpik River	18.8	206	145	32.2	0.0
North Fork Kalikpik R.Trib.	0.5	86	84	21.6	0.0
Ublutuoch River	14.4	192	130	11.4	0.4
Kealok Creek	23.6	230	165	31.5	0.0
Teshekpuk Lake Tributary	12.0	102	120	15.9	0.0

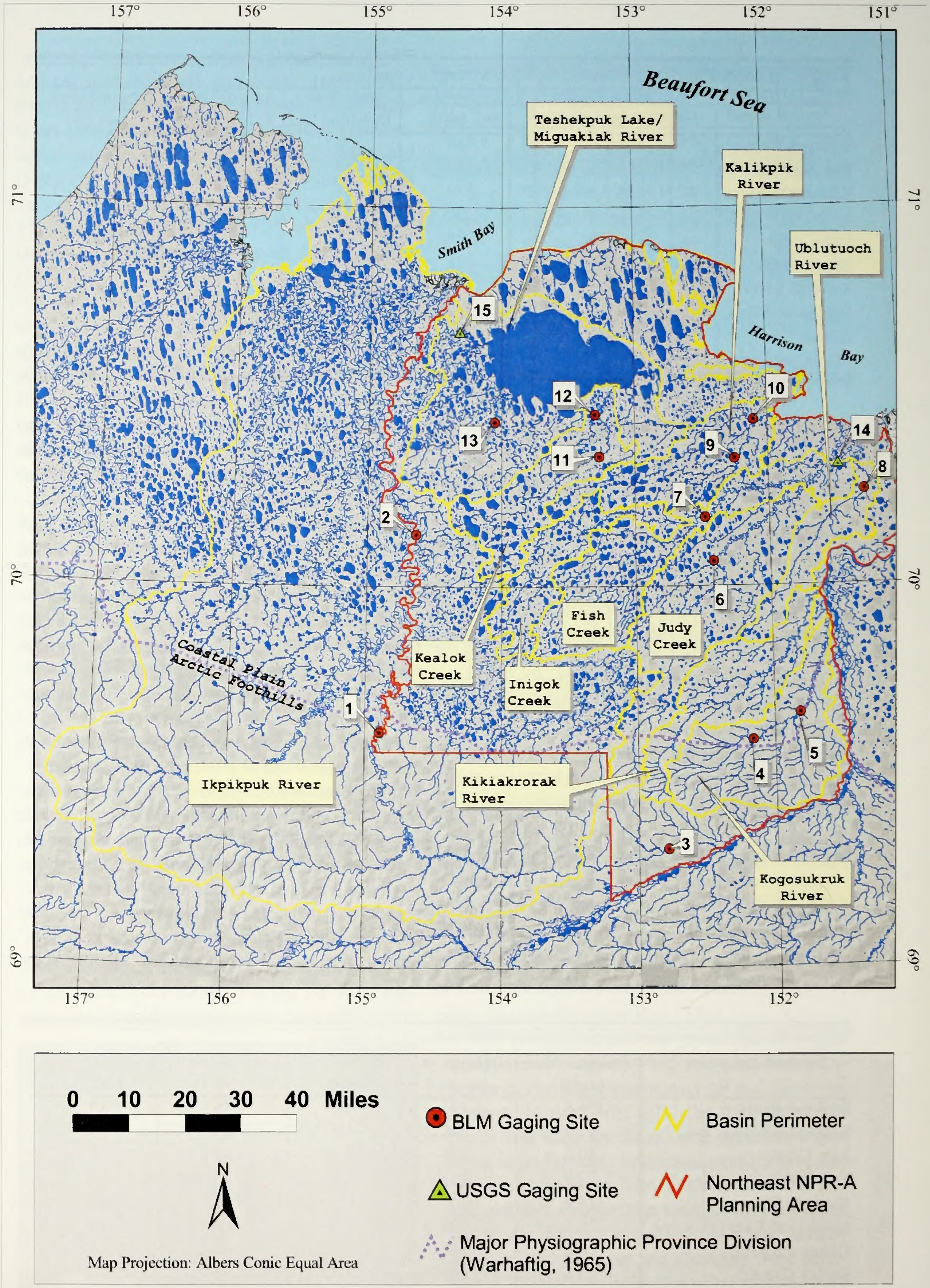

Figure 5. Hydrologic basin map.

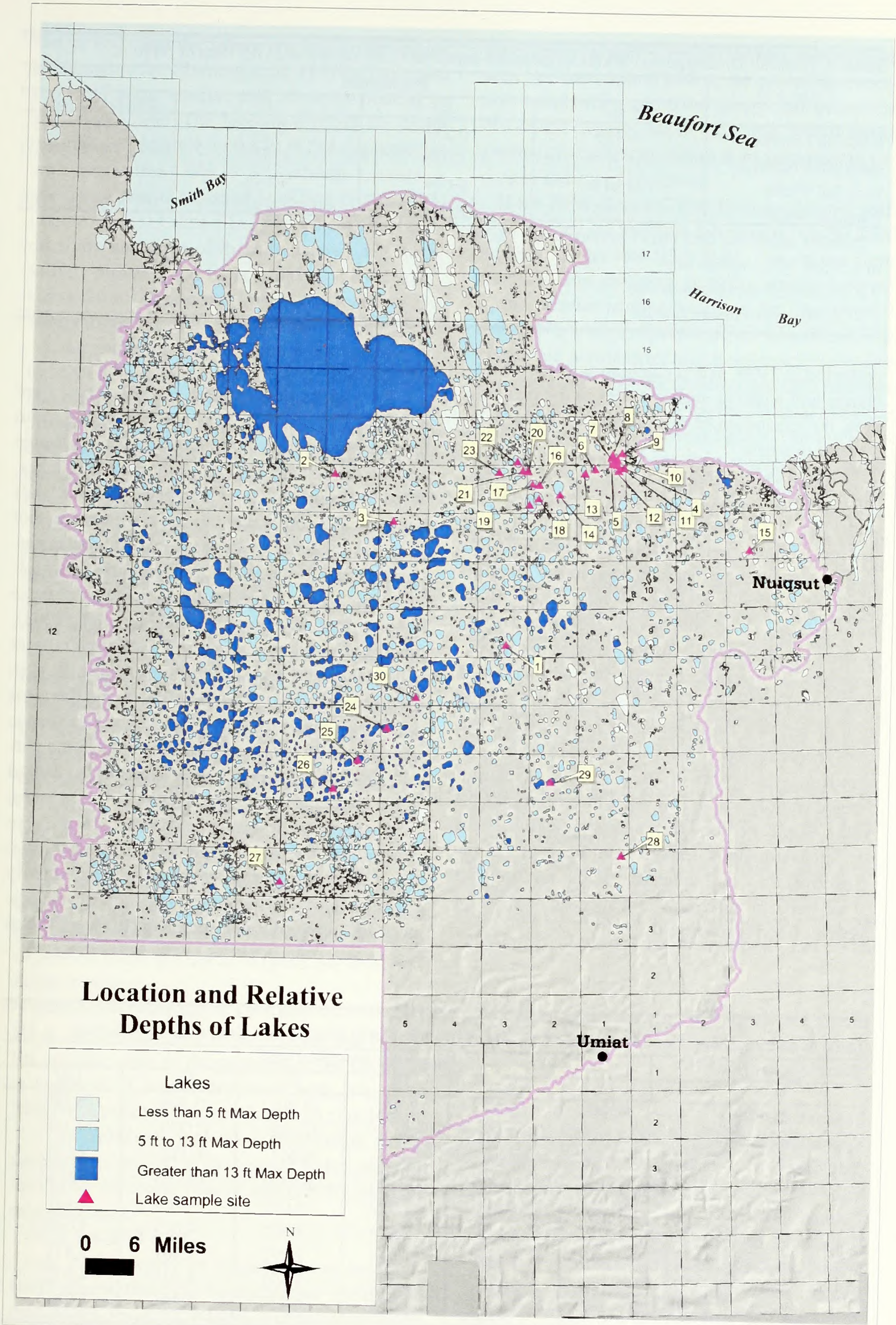

Figure 6. Location map for lakes in Northeast NPR-A.

Table 5. Bankfull Discharge and Width Regressions based on Field Survey and GIS Data of NPR-A.

Gage Site	Parameters			
	m	b	r^2	Standard error
Bankfull Discharge	6.125	0.237	0.765	0.577
Bankfull Discharge*	10.677	1.026	0.859	0.521
Bankfull Width	3.843	0.694	0.642	0.477
Bankfull Width*	5.220	0.634	0.763	0.443

* Includes additional data from Childers et al. (1978)
m = Slope of regression line
b = Y-intercept of regression line
r^2 = Coefficient of determination

collected in 1999. When calculating bankfull discharge and width at ungaged sites in the planning area, the second set of regressions would provide a better estimate.

Table 6 lists the flood frequency discharges computed from the regional estimator equations (Jones and Fahl 1995) and the basin characteristics in Table 4. While some authors have attempted to assign a given recurrence interval to the bankfull discharge (usually a 1.5- or 2-year flood), Williams (1978), in an analysis of 233 stream sites, found that the bankfull discharge does not have a common recurrence frequency. The field-surveyed bankfull discharges (Table A-3), with the exception of the two Kalikpik River sites, exceed the two-year recurrence interval floods (Table 6). The recurrence intervals of the bankfull discharge ranged from less than two years to greater than 50 years. While the flood recurrence values used here are approximations derived from the regional regressions, they still indicate that the relationship of the bankfull discharge to a specific recurrence interval flood is uncertain.

Water Quality

The results of the water quality surveys are listed in Appendix B. The Arctic Coastal Plain between the northern foothills of the Brooks Range and the Arctic Ocean contains thousands of lakes. What little sampling has taken place on these lakes has been at a single point in time, which does not provide any sense of the seasonal or annual patterns of flux in the lakes or mechanisms controlling any change. The most broad-reaching of these types of studies is recorded in Kling et al. (1992), where the researchers surveyed a 250 km transect of 45 lakes and eight rivers from Atigun Pass in the Brooks Range to Prudhoe Bay on the Beaufort Sea. They found that the presence of continuous permafrost, the geological differences in the parent material and the proximity to the sea explained much about the ionic regime in the different lakes.

In general, the waters in northeastern NPR-A are pristine and the parameters recorded during the two trips reflect this. During June the rivers had slightly higher pH and dissolved oxygen, and lower temperature and conductance compared to July (Tables

Table 6. Instantaneous Flood-Frequency Calculated from Regional Regressions (Jones and Fahl 1994).

Stream Survey Site	Recurrence Interval (yrs)					
	2	5	10	25	50	100
Ikpikpuk River	9,646	14,499	17,552	21,401	23,898	26,379
Kogosukruk River	4,335	6,766	8,353	10,400	11,770	13,148
Judy Creek	2,724	4,351	5,459	6,961	8,032	9,155
Fish Creek	5,154	8,236	10,285	12,960	14,796	16,653
Ublutuoch River	1,412	2,384	3,072	4,016	4,704	5,427
Kalikpik River	1,179	1,998	2,584	3,405	4,015	4,669
North Fork Kalikpik R.Trib	686	1,188	1,555	2,072	2,461	2,877
Kealok Creek	1,250	2,117	2,736	3,603	4,245	4,932
Teshekpuk Lake Tributary	776	1,350	1,766	2,349	2,781	3,241

B-1 & B-2), but the values are within the ranges encountered by Childers et al. (1978). Lake and river pH were similar and all were neutral to slightly alkaline. The lakes and rivers are dilute (average conductivity of 0.170, 0.148 respectively) with ranges from .069 to .372 mS/cm-1, which is similar to results reported by Kling et al. (1992) (.030 to .843). Lakes 5 to 10 had the highest conductivity and three of these registered detectable salinity probably due to the proximity to the coast. Lakes 26 to 29 had the lowest conductivity and were farthest from the coast (Table B-3).

Lake and river temperatures were very similar in July and averaged around 14°C. In general the lakes were slightly oversaturated with oxygen, probably due to high productivity of algae. CO_2 is slightly greater than atmospheric, meaning that the lakes are a small source of CO_2 to the atmosphere (Table B-5).

In the nine lakes analyzed, total phosphorous (TP) ranges from 0.005 to 0.023 mg/L, with a mean of 0.0115 mg/L, which is in the oligo-mesotrophic to meso-eutrophic range (Table B-4). In the one river analyzed, TP fell in the same range as the lakes. Inorganic soluble phosphorous ranged between 0.002 and 0.006, with a mean of 0.0031 mg/l. This type of phosphorous is the most important to the phytoplankton and is rapidly recycled.

The forms of nitrogen measured were nitrite-nitrate (NO_2 and NO_3) and ammonium-nitride (NH_3-N), also listed in Table B-4. These values were relatively high compared to Gregory-Eaves et al. (2000).

The stable isotopes of oxygen and hydrogen in water are reported relative to arbitrary standards of Standard Mean Ocean Water (SMOW) and are expressed in the per mil o/oo (parts per thousand) notation where:

$\delta R(o/oo) = (Ra/Rstd - 1) \times 1000$

Ra is the isotopic ratio of the sample and Rstd is the isotopic ratio of the standard. If the δR value is negative, it means depletion with respect to SMOW. A positive value indicates an enrichment.

A correlation between depletion of D (dueterium) and ^{18}O in fresh water is described by the Global Meteoric Water Line (GMWL) and the relationship is:

$\delta D = 8 \times \delta^{18}O + 10$

Due to the degree of evaporation or local climatic effects, there can be significant variation in the GMWL resulting in local or regional meteoric water lines. Deviations from GMWL, such as those seen in closed inland basins, are caused by excessive evaporation and these points fall below the line on the oxygen side of the graph. This is due to greater kinetic fractionation in oxygen than in hydrogen during evaporation.

If the NPR-A data (Table B-6) are plotted with $\delta^{18}O$ against δD, the data fall roughly on the local meteoric water line (Fig. B-6). The values from foothills sites are more negative (more depleted in the heavier isotopes), due to the "continental effect." As a storm system moves inland from the ocean and across drier and more topographically diverse terrain, the precipitation that falls removes the heavier isotopes, leaving the residual moisture in the air mass progressively lighter. The snow and rain that fall inland are then isotopically lighter than the coastal precipitation as reflected in the lake isotope values. Rivers that drain the more interior regions are also isotopically lighter (more negative) than coastal rivers. Several of the lake samples fall slightly to the right of the meteoric water line, indicating higher evaporation in these lakes as compared to the other sampled lakes.

Zooplankton diversity in the Arctic is relatively low. Kling et al. (1992) found only 11 species of zooplankton in their study. Similary, the species found here are represented by the same groups: Cladocera, Amphipoda, Copepoda, Chydoridae, Ostracoda, Bosmia and Rotifera. The lakes were very different in species composition. Lake 1 had mostly copepods *(Diaptomus and Cyclopoids)*, as well as Cladocera and Chydoridae. Lake 2 had mostly Cladocera *(Daphnia middenorphian)* but also had Cyclopoida and *Diaphtomus* copepods, chydorids, ostracods and brachiopods. Lake 3 had

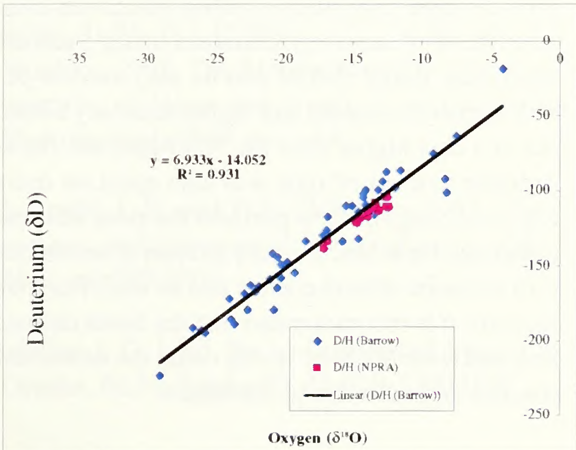

Figure 7. Isotope plot of NPR-A lakes and rivers.

only insect larvae (chironomids) and smaller zooplankton (ostracods, cyclopoids and Chydoridae), indicative of a lake supporting fish. Lake 6 had large amphipods *(Gamerus sp.)* and abundant bright orange Diaptomidae copepods full of eggs. There were also Chydoridae and chironomids. This lake is most probably devoid of fish. While lake 4 had chironomid larvae as well as other dipteran larvae, the rest of the zooplankton were very small in size (Chydoriae, Bosmia and small copepod larvae), a strong indication of fish in the lake. Lake 30 had abundant detritus with just small zooplankton such as rotifers, Copepodae and Chydoriae. There was also a polychaete found in this sample, probably *Marenzellaria sp.*

Molluscs (dead shells of *Pisidium*) were found in lakes 13, 17-19, 22, 24-26, 29-30. Although no fish sampling was attempted, dead fish were found in lakes 14, 16, 18. The fish in lake 16 was an adult ninespine stickleback, *Pungitius pungitius* (Linneaus).

RECOMMENDATIONS

Geographic Information System

The use of GIS was inefficient in this project, largely due to limitations in available data, hardware and software. Changes that will help correct these problems are imminent.

The currently available digital elevation models do not provide adequate resolution to capture the necessary terrain details on the North Slope of Alaska. Because of this, an inordinate amount of time was spent manually editing the GIS-derived basins for this project. The National Elevation Dataset (NED) in production by USGS is likely to provide some improvement when it becomes available. Remote sensing techniques using Synthetic Aperature Radar (SAR) can be also used to provide higher resolution and higher accuracy DEMs, but at a cost higher than the NED data set. An inordinate amount of time was also spent on deriving river centerlines to perform the river mile calculations. New functionality in soon to be released GIS software should correct this as well. For these reasons, it is recommended that the basin delineation and river miles be re-run using the newer data sources and software in the future.

Hydrology

The data and statistical calculations presented here should be considered preliminary. Direct measurements of peak flow during spring breakup would provide more reliable flood estimates than computer-generated discharges. Data gathered from stream-level recorders (automated data loggers with pressure transducers) during ice breakup, combined with streamflow measurements, would provide a complete record of the flood events that account for 70% or more of the annual discharge (Sloan 1977). Collecting five or more years of peak-flow data at selected sites would provide a reliable database as well as allow computation of flood-recurrence statistics that meet state and federal guidelines (Alaska DNR 1984, Childers 1970). Surveying more stream reaches for hydraulic geometry relationships would increase the reliability of the channel geometry regression equations, providing a more accurate environmental evaluation for permitted activities.

Water Quality

Sampling over the course of the summer for several years would not only provide baseline data, but would allow the determinations of seasonal and annual patterns of change in the lakes and rivers as well as give an insight into mechanisms controlling these changes. Samples taken in late winter (March-April) would verify overwintering habitat viability.

It would be useful to take surface sediments from some of these lakes to develop diatom calibration sets. This would be useful for determining any past climate and environmental changes through downcore sediment analysis in this region and would allow for monitoring of any future changes in lake ecosystems.

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Appendix A: Discharge Data at River Survey Sites

Table A-1. Discharge Measurements from July 6-10, 1999.

Stream Site	Discharge (cfs)	Max. Depth (ft)	Mean Vel. (fps)	Width (ft)	Runoff (cfsm)
Ikpikpuk River	30	1.2	1.7	24	0.03
Kogosukruk River	11	0.6	0.7	39	0.02
Judy Creek	69	1.9	0.9	68	0.16
Fish Creek	589	3.6	1.4	232	0.86
Kalikpik River	157	3.1	1.6	52	0.76
No. Fork Kalikpik River Trib.	43	3.0	0.5	45	0.50
Ublutuoch River	44	1.5	2.2	18	0.23
Kealok Creek	182	2.3	1.8	61	0.79
Teshekpuk Lake Tributary	38	1.1	1.0	55	0.37

Table A-2. Peak Streamflow Computed from June Floodmarks, Surveyed July 1999.

Stream Site	Discharge (cfs)	Max. Depth (ft)	Mean Vel. (fps)	Width (ft)	Runoff (cfsm)
Ikpikpuk River	6,920	7.5	3.3	435	5.89
Kogosukruk River	4,320	8.6	4.6	165	9.68
Judy Creek	1,380	5.8	1.6	310	3.17
Fish Creek	3,690	6.2	2.4	481	5.41
Kalikpik River	626	4.6	3.6	63	3.04
No. Fork Kalikpik River Trib.	550	6.5	2.0	64	6.37
Ublutuoch River	2,670	12.3	4.3	90	13.91
Kealok Creek	940	3.7	3.0	189	4.09
Teshekpuk Lake Tributary	1,360	5.2	2.3	152	13.35

Table A-3. Estimate of Bankfull Discharge.

Stream Site	Discharge (cfs)	Max. Depth (ft)	Mean Vel. (fps)	Width (ft)	Runoff (cfsm)
Ikpikpuk River	13,400	9.1	4.8	438	11.40
Kogosukruk River	12,700	14.6	6.6	199	28.47
Judy Creek	5,060	9.2	2.6	353	11.61
Fish Creek	10,500	9.2	3.4	512	15.38
Kalikpik River	1,040	5.3	4.5	83	5.05
No. Fork Kalikpik River Trib.	550	6.5	2.0	64	6.37
Ublutuoch River	3,000	13.2	4.3	98	15.63
Kealok Creek	2,950	5.3	4.5	254	12.84
Teshekpuk Lake Tributary	2,340	7.7	2.3	186	22.97

Appendix B: Water Quality Survey Data

Table B-1. Water Quality Readings from NPR-A Rivers on June 11, 1999.

Stream Site	Temperature (°C)	Specific Conductance (ms/cm)	pH	Dissolved Oxygen (mg/L)
Ikpikpuk River	11.6	0.034	8.1	13.10
Lower Ikpikpuk River*	>.8	0.035	8.4	14&10
Upper Kogosukruk River*	11.5	0.042	8.0	13.30
Prince Creek*	13.1	0.018	7.5	11.50
Judy Creek	10.6	0.055	8.2	13.60
Fish Creek	5.3	0.045	8.3	15.50
Kalikpik River	4.6	0.036	7.8	16.60
Lower Kealok Creek*	2.5	0.046	7.8	17.10
Teshekpuk Lake Tributary	1.0	0.027	8.0	17.10

* Site not revisited during July trip.

Table B-2. Water Quality Readings from NPR-A Rivers on July 6-11, 1999.

Stream Site	Temp (°C)	Specific Conductance(ms/cm)	pH	Dissolved Oxtgen (mg/L)	Turbidity $ NTU	Salinity Percent
Ikpikpuk River	17.7	0.145	7.60	11.00	18	0
Kogosukruk River	17.7	0.223	7.89	11.27	10	0
Judy Creek	12.1	0.131	7.72	11.88	7	0
Fish Creek	13.2	0.108	7.78	12.14	11	0
Kalikpik River	12.9	0.159	7.46	12.16	5	0
North Fork Kalikpik R.Trib.	14.8	0.175	7.49	11.75	15	0
Ublutuoch River	16.0	0.109	7.18	11.47	2	0
Kealok Creek	11.6	0.111	7.55	12.09	12	0
Teshekpuk Lake Tributary	11.3	0.167	7.70	12.22	18	0

Table B-3. Water Quality of NPR-A Lakes on July 6-11, 1999.						
Lake Site	Temperature (°C)	Specific Conductance (ms/cm)	pH	Dissolved Oxygen (mg/L)	Turbidity NTU	Salinity Percent
1	18.0	0.152	7.96	12.07	0	0.00
2	12.2	0.161	7.73	11.11	0	0.00
3	12.7	0.100	7.58	11.99	0	0.00
4	17.1	0.135	7.60	10.98	2	0.00
5	13.6	0.372	7.96	11.67	1	0.01
6	13.6	0.232	7.90	11.87	0	0.00
7	14.3	0.272	7.58	11.90	15	0.01
8	12.3	0.317	7.52	12.75	3	0.01
9	13.8	0.190	7.30	12.23	0	0.00
10	12.1	0.261	7.77	12.70	0	0.01
11	13.4	0.083	7.17	12.07	2	0.00
12	12.4	0.111	7.28	12.49	3	0.00
13	13.7	0.183	7.69	12.27	3	0.00
14	13.2	0.183	7.73	12.28	20	0.00
15	15.5	0.164	7.30	10.64	8	0.00
16	16.7	0.151	8.19	11.83	0	0.00
17	14.1	0.183	7.72	12.50	2	0.00
18	15.5	0.188	7.78	11.76	0	0.00
19	16.5	0.184	7.87	12.26	0	0.00
20	15.5	0.215	7.92	11.82	2	0.00
21	13.8	0.189	7.77	12.77	4	0.00
22	17.0	0.162	7.81	12.04	7	0.00
23	14.3	0.170	7.80	12.94	2	0.00
24	13.8	0.121	7.63	12.06	0	0.00
25	14.5	0.161	7.91	11.72	0	0.00
26	13.3	0.099	7.63	12.39	0	0.00
27	16.3	0.081	7.54	11.33	22	0.00
28	16.2	0.081	7.54	11.33	22	0.00
29	15.6	0.069	7.30	11.70	7	0.00
30	12.2	0.131	7.53	12.48	0	0.00

Table B-4. Miscellaneous Water Quality Constituents of NPR-A Lakes and Rivers, July 6-11, 1999.

Site	Unfiltered Total-P mg/l	Dissolved PO_4-P mg/l	NO_3-N +NO_3-N mg/l	NH_3-N mg/l	Dissolved K mg/l	Dissolved Ca mg/l	Dissolved Mg mg/l	Dissolved Fe mg/l	Dissolved Si mg/l
Lake 1	0.006	0.402	0.051						
Lake 2	0.009	0.003	0.301	0.036	0.39	24.40	2.684	*0.08	*0.9
Lake 3	0.011	0.003	0.058	0.043	0.35	14.60	1.600	*0.04	*1.3
Lake 6	0.013	0.004	0.441	0.040	1.01	26.50	5.480	*0.02	*0.9
Lake 14	0.005	*0.001	0.209	0.025	0.50	25.20	2.845	*0.02	*1.0
Lake 26	0.023	0.002	0.128	0.043	0.42	13.40	1.590	*0.03	*0.9
Lake 28	0.015	0.002	0.461	0.045	0.48	24.30	3.110	*0.03	*1.2
Lake 29	0.008	0.003	0.308	0.033	0.28	10.41	1.458	*0.03	*0.7
Lake 30	0.008	0.002	0.420	0.031	1.27	20.10	1.780	*0.00	*0.8
Kogosukruk River	0.014	0.003	0.723	0.019	2.03	28.80	5.330	*0.07	3.8

*Value below verifiable detection limits.

Table B-5. Carbon Dioxide Values of NPR-A Lakes, July 6-11, 1999.

Lake Site	CO_2 (water) ppm	CO_2 (air) ppm
Lake 1	1,793*	
Lake 2	404	390
Lake 3	356	368
Lake 4	426	
Lake 5	431	
Lake 6	359	
Lake 7	425	
Lake 8	530	
Lake 9	377	
Lake 10	395	
Lake 11	497	
Lake 12	440	
Lake 13	390	
Lake 14	455	
Lake 15	706	
Lake 16	441	
Lake 17	403	

*While this sample is in the range of values found elsewhere, it may be an anomaly due to sampling or laboratory error.

Table B-6. Isotope Values of NPR-A Lakes and Rivers, July 6-11, 1999.

Site	Oxygen $\delta^{18}O$*	Deuterium δD*
Lake 1	-14.8	-120
Lake 2	-14.4	-118
Lake 3	-13.8	-113
Lake 9	-12.7	-104
Lake 12	-13.4	-108
Lake 15	-13.3	-111
Lake 17	-12.5	-104
Lake 23	-13.9	-113
Lake 26	-12.6	-110
Lake 28	-12.4	-110
Lake 29	-13.1	-113
Lake 30	-13.9	-117
Ikpikpuk River	-16.8	-133
Kogosukruk River	-17.1	-138
No.Fk. Kalikpik R.Trib.	-13.3	-111
Teshekpuk Lake Trib.	-14.7	-121

*Analytical precisions (1 sigma.)= 0.08 for $\delta^{18}O$ and 0.9 for δD

Appendix C: Stream Reference Sites

Figure C-1. Ikpikpuk River looking upstream from the survey site. This river originates at the confluence of the Kigalik River and Maybe Creek in the foothills just north of the Colville River. The Ikpikpuk River is the largest river on the North Slope that originates within the foothills province. The cross section is just north of the foothills/coastal plain boundary.

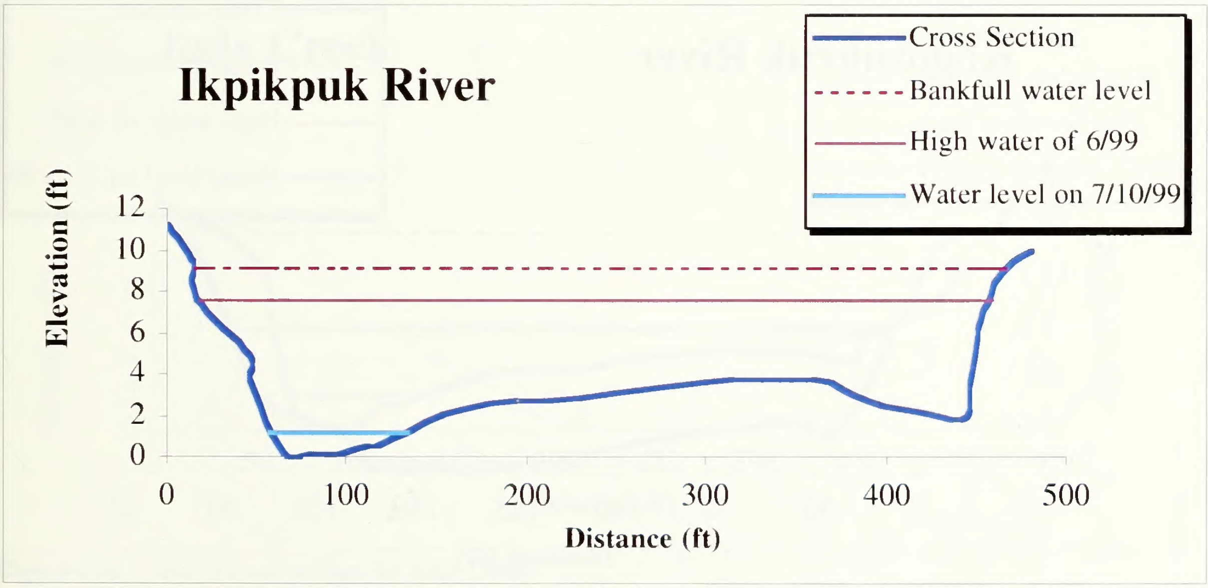

Figure C-2. Channel cross section Ikpikpuk River.

Figure C-3. Kogosukruk River looking downstream. It originates in the foothills north of Umiat, flows north-east parallel to the Kikiakrorak River, where both are tributaries to the Colville River. The cross section is on a reach of the river that has become entrenched within the meanders, creating cliff-like bluffs that are important raptor habitat (see figure 4).

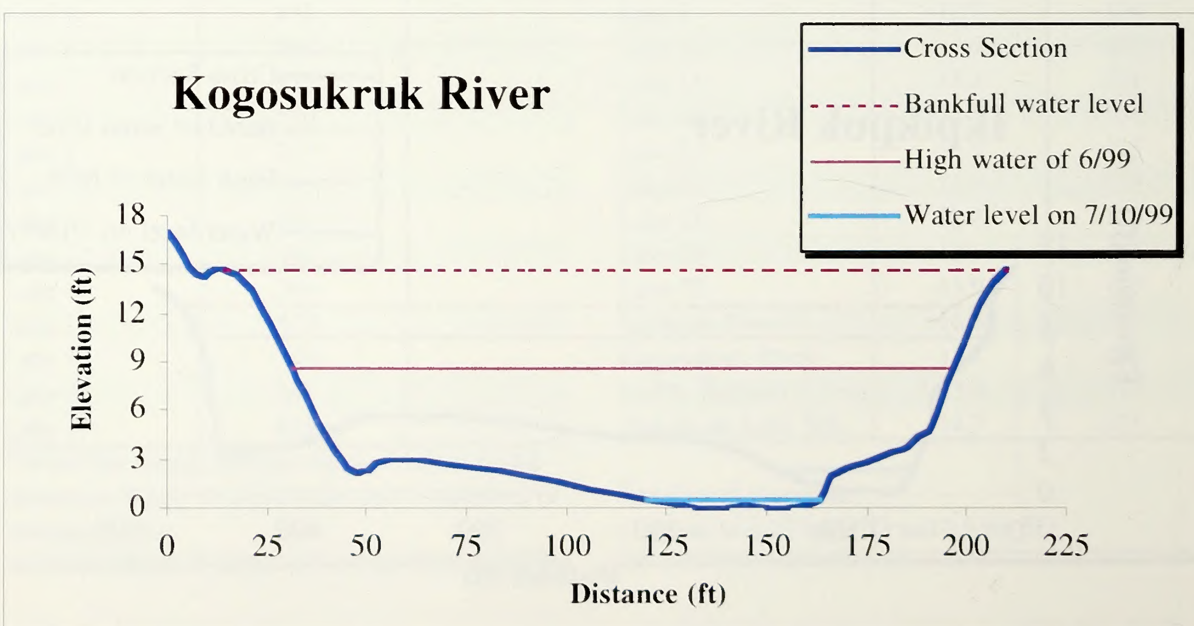

Figure C-4. Channel cross section for Kogosukruk River.

Figure C-5. Judy Creek cross section at center of photo is in the coastal plain, but the creek originates in the foothills northwest of Umiat. In this lower reach the stream is indistinguishable from Fish Creek. Judy Creek flows into Fish Creek about 20 miles downstream of the survey site.

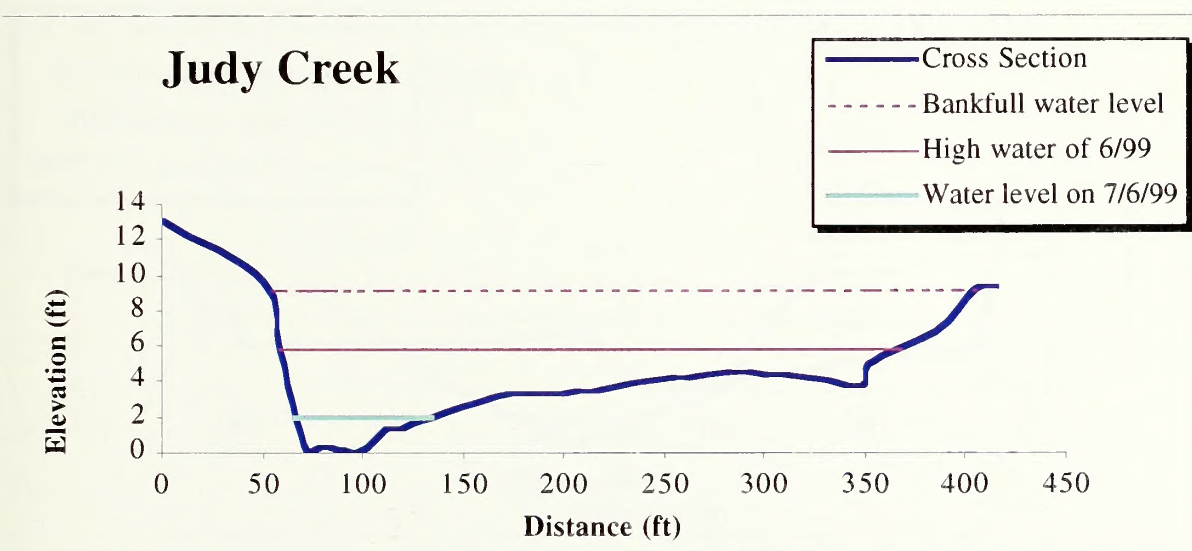

Figure C-6. Channel cross section for Judy Creek

Figure C-7. Photo of Fish Creek looking downstream from the survey site. This stream originates entirely within the coastal plain and flows northeast into Harrison Bay. The second largest drainage basin within the planning area, Fish Creek had the highest flow measured during July and is one of the most important drainages for subsistence fisheries.

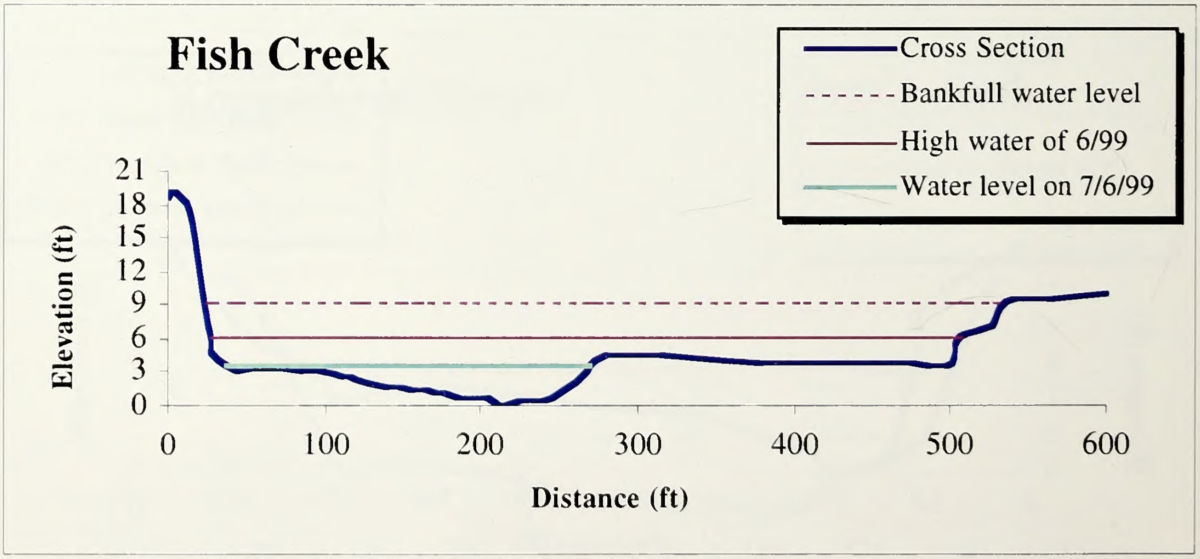

Figure C-8. Channel cross section for Fish Creek.

Figure C-9. Ublutuoch River looking downstream; the survey site is below the bend. This stream differed from all the others surveyed in that it had few sand and gravel bars and vegetation was growing down to the low-water channel for most of the reach.

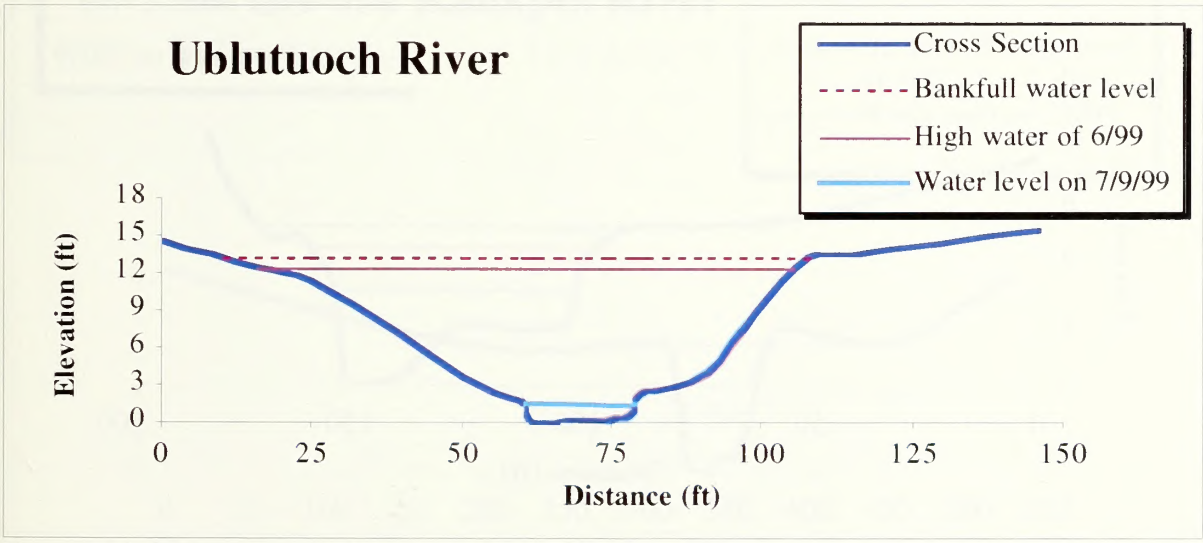

Figure C-10. Channel cross section for Ublutuoch River.

Figure C-11. Kalikpik River looking upstream from the survey site. The bluffs in the background are stabilized sand dunes that contribute sediment to the braided, sand channel. The Kalikpik River also supports an important subsistence fishery.

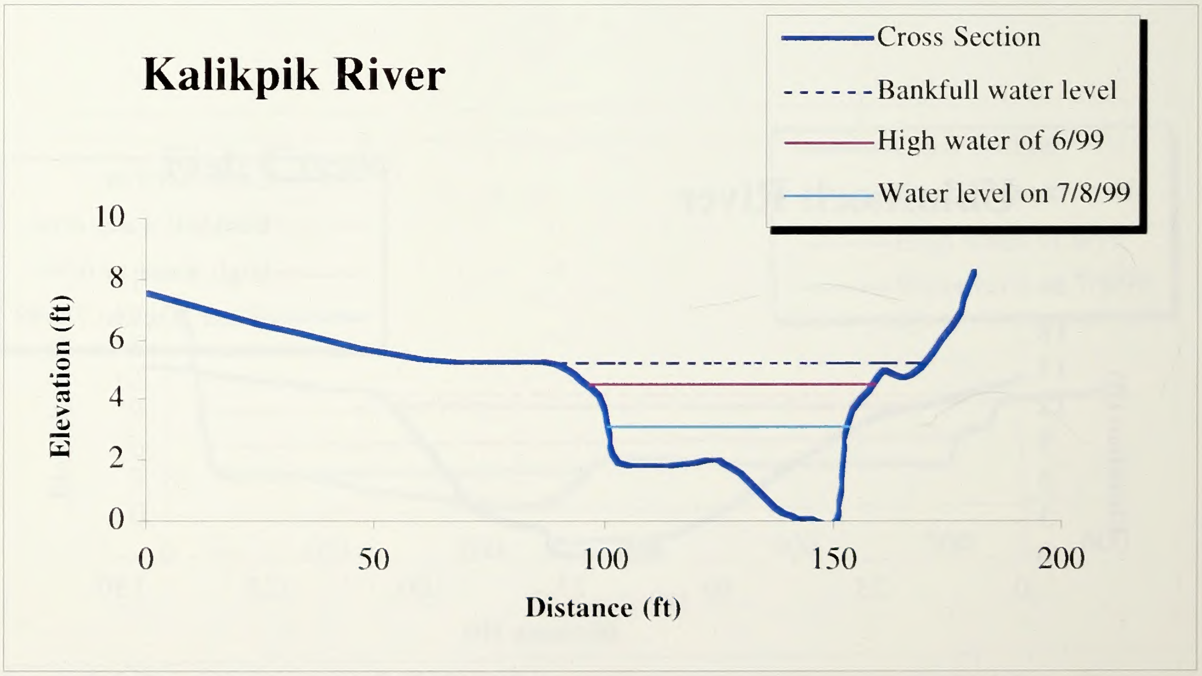

Figure C-12. Channel cross section for Kalikpik River.

Figure C-13. North Fork Kalikpik River's tributary, looking downstream. The largest tributary of the Kalikpik River, this stream is interconnected to numerous lakes that support fish.

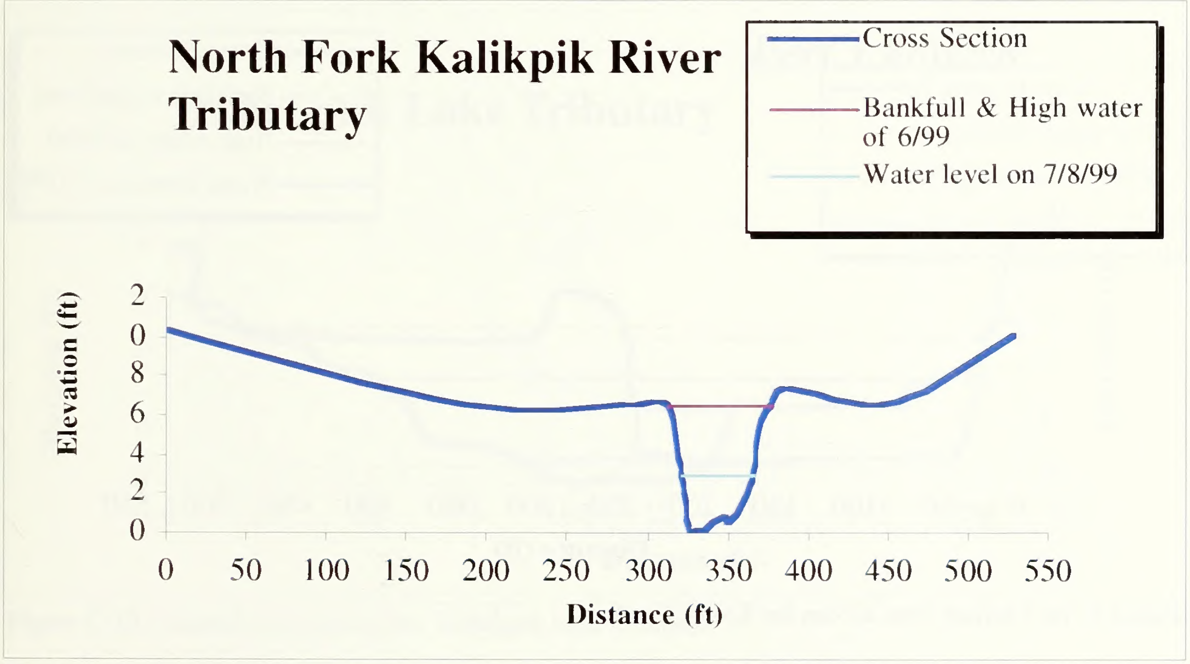

Figure C-14. Channel cross section for North Fork Kalikpik River tributary.

Figure C-15. Kealok Creek looking downstream at the survey site. This creek originates in the stabilized sand dunes south of Teshekpuk Lake. As the largest tributary to this lake, it had the second highest streamflow measured during July.

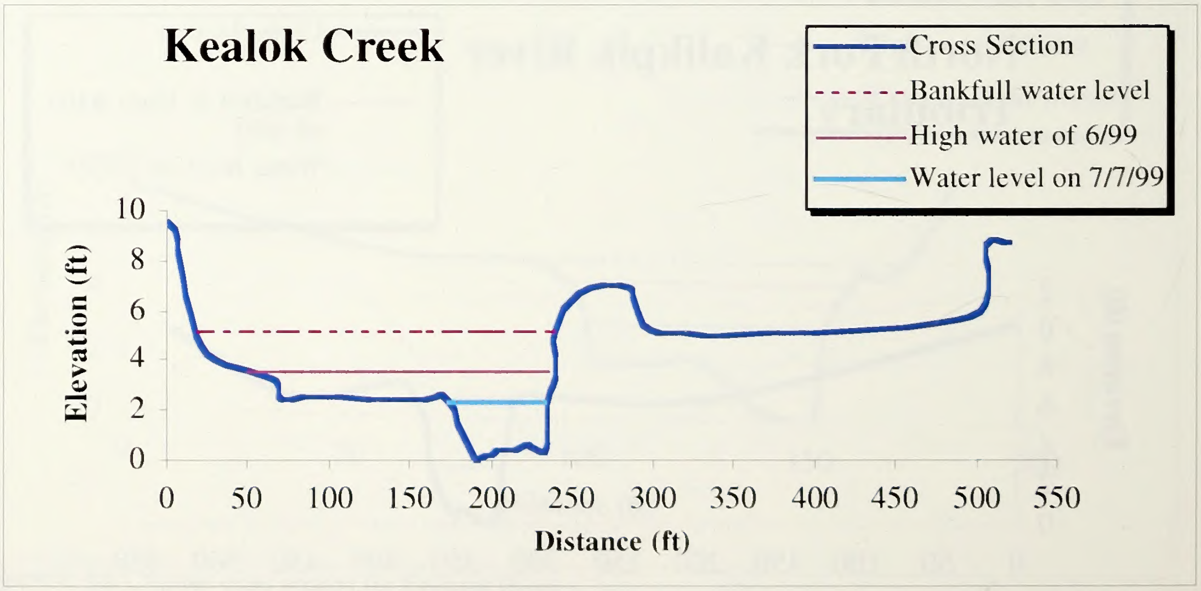

Figure C-16. Channel cross section for Kealok Creek.

Figure C-17. Teshekpuk Lake tributary looking downstream. The second largest tributary to Teshekpuk Lake after Kealok Creek, this stream also originates in the dune area south of the lake.

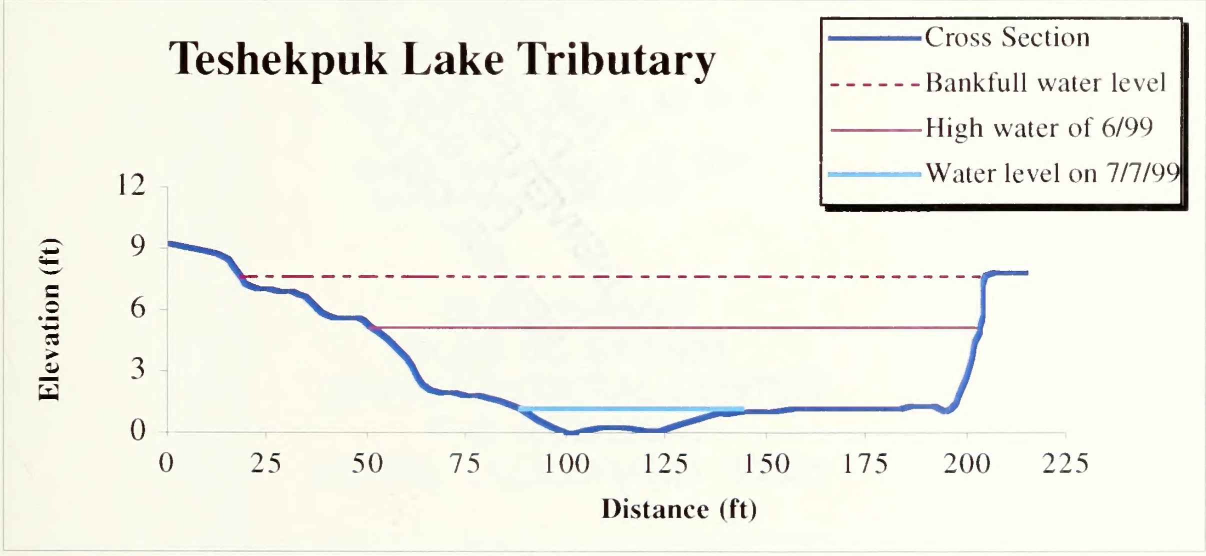

Figure C-18. Channel cross section for Teshekpuk Lake tributary.